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ASSESSMENT OF THE IMPACTS OF LEAKS IN THE MARBLE FALLS SEWAGE SYSTEM ON WATER QUALITY IN MILL CREEK AND THE BUFFALO RIVER.

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About the Author

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Mr. Aley has over 46 years of professional experience in groundwater hydrology with major focus on the interaction of surface and subsurface waters in karst landscapes and on groundwater tracing studies using fluorescent dyes. He has directed a number of hydrology studies in northern Arkansas and elsewhere in the Ozarks. He is the founder and president of the Ozark Underground Laboratory, a consulting and contract studies firm that works throughout the United States with some foreign work in Australia, Asia, South America, and the Caribbean. He has published extensively in professional publications. A complete copy of his resume is found at www.ozarkundergroundlab.com.

Introduction

The sewage system serving the Marble Falls Sewer Improvement District #1 has experienced severe leakage and system failures that have, among other things, resulted in raw sewage discharges into Mill Creek (Aley 2009). Mill Creek is a major tributary to the Buffalo River. While some repairs have been made to the sewage system subsequent to the 2009 study, multiple and extensive other problems with severe water quality impacts exist within the sewage system.

Litigation has been filed by the Arkansas Department of Environmental Quality (ADEQ) against the Marble Falls Sewer Improvement District #1 (Marble Falls sewage system). A preliminary injunction consent decree was issued in the Circuit Court of Newton County, Arkansas related to problems with the Marble Falls sewage system. This decree led to an engineering study conducted by ESI (2010) and the introduction of tracer dyes into portions of the sewer system by ADEQ (2010).

The National Park Service (NPS) is responsible for protecting public health and safety on the Buffalo National River, and Mill Creek is a major tributary to the river. The discharge of untreated or inadequately treated sewage into Mill Creek poses a health risk, and potentially a health hazard, to Park visitors. The NPS needs a good understanding of the risks/hazards posed by the sewage system at Marble Falls in order to meet their responsibilities and guide their management. The purpose of this report is to provide this information. This report is primarily based upon previous studies and the recent reports by ESI (2010) and ADEQ (2010).

Hydrogeologic Setting

Almost all of the Marble Falls sewage system is underlain by a well-developed and rapidly transmissive karst groundwater system (Aley and Aley 2000). Lower Dogpatch Spring, one of the largest springs in the Buffalo River basin, discharges to Mill Creek within the area of the former Dogpatch Theme Park. A major karst hydrology and groundwater tracing study of the region (Aley and Aley 2000) delineated the recharge area for this spring and found it to include an area of 10.90 square miles. Twenty percent of this recharge area is within the Mill Creek topographic basin and the other 80% is within the Crooked Creek topographic basin. Most of the area where present users of the Marble Falls sewer system are located is within the delineated recharge area for Lower Dogpatch Spring. However, with the exception of a groundwater trace from the Mill Creek channel adjacent to lift station 1 serving the Marble Falls sewage system (Aley 2009), none of the dye traces to Lower Dogpatch Spring were from locations served by this sewage system.

Upper Dogpatch Spring is located adjacent to the former Dogpatch Theme Park and approximately 1,500 feet north-northwest of Lower Dogpatch Spring. The delineated recharge area for this spring (Aley and Aley 2000) encompasses 4.82 square miles with 29% of this within the Mill Creek topographic basin and the remainder within the Crooked Creek topographic basin.

On October 21, 2009, the Ozark Underground Laboratory introduced four pounds of rhodamine WT dye mixture containing a 20% dye equivalent into raw sewage sinking in the otherwise dry channel of Mill Creek immediately downhill of the Marble Falls sewage lift station 1 (Aley 2009). This lift station had been inoperable for approximately 9 months following an ice storm in late January 2009. That storm interrupted electric service and it is my understanding that the pump at lift station 1 was submerged in raw sewage and rendered useless. During the dye tracing study in October 2009 all of the dye and raw sewage entered the groundwater system within a few feet of the dye introduction point. The dye was subsequently detected in water discharging from both Upper and Lower Dogpatch Springs. Aley (2009) estimated that about 97% of the detected dye discharged from Lower Dogpatch Spring and the remaining 3% discharged from Upper Dogpatch Spring. Dye was first detected less than 21 hours after dye introduction in an activated charcoal sampler from a sampling station (Station 5) downstream of Lower Dogpatch Spring and downstream of a series of three ponds on Mill Creek. The peak dye concentration at Station 5 occurred between about 21 and 46 hours after dye introduction.

Dye from the October 21, 2009 introduction also discharged from Upper Dogpatch Spring. This spring is located about 2,500 feet straight-line distance from the dye introduction point. The first dye detection at this sampling station occurred between 21 and 46.5 hours after dye introduction. While Lower Dogpatch Spring is further from the dye introduction point (about 3,200 feet) than Upper Dogpatch Spring, the dye arrived at Lower Dogpatch Spring earlier than at Upper Dogpatch Spring.

Groundwater tracing reported in Aley and Aley (2000) and Aley (2009) clearly demonstrate rapid groundwater flow in the karst groundwater system supplying the two Dogpatch Springs. This is the same groundwater system that underlies a substantial part of the Marble Falls sewage system. Such flow systems provide ineffective natural cleansing and can readily transport bacteria, viruses, and other pathogens.

Both Upper and Lower Dogpatch Springs discharge from the St. Joe Limestone member of the Boone Formation (Hudson 1998; Hudson et al. 2001 and 2004; Aley and Aley 2000). The St. Joe Limestone is at the base of the Boone Formation and about 50 feet thick in the study area (Hudson et al. 2001 and 2004). In the study area this formation is underlain by the Everton Formation which consists of interbedded sandstone, limestone, and dolomite. The Everton Formation is less subject to dissolution and the development of preferential groundwater flow routes than is the overlying Boone Formation (Aley and Aley 2000).

Aley and Aley (2000) tabulated flow rate measurements made of both Upper and Lower Dogpatch Springs during the period from May 1968 through May 1988. The values are summarized in Table 1.

Table 1. Summary of flow rate measurements at Upper and Lower Dogpatch Springs (Aley and Aley 2000). Cubic feet per second = cfs. Gallons per minute = gpm.

Upper Dogpatch Spring	
Minimum Measured Flow Rate	0.9 cfs (404 gpm)
Maximum Measured Flow Rate	12.6 cfs (5,657 gpm)
Mean Measured Flow Rate	4.3 cfs (1,931 gpm)
Number of Measurements	5
Lower Dogpatch Spring	
Minimum Measured Flow Rate	1.9 cfs (853 gpm)
Maximum Measured Flow Rate	37.5 cfs (16,838 gpm)
Mean Measured Flow Rate	10.57 cfs (4.746 gpm)
Number of Measurements	6

Typically about 75% of the annual precipitation that falls on karst units in the Ozarks moves into and through the groundwater system before reaching one of the perennial streams in the area (Aley 1977). This value is reasonable for the Boone Formation in the area traversed by the sewer lines serving the Marble Falls sewer system. Travel rates for the movement of water into and through karst groundwater systems in the Ozarks are routinely hundred to thousands of feet per day and most of the waters routinely receive ineffective natural cleansing.

It is difficult to locate most leakage points from sewer lines and sewage ponds in karst landscapes such as the area served by the Marble Falls sewage system. This is because most of the leakage moves downward into the karst groundwater system without first surfacing somewhere near the leakage point. Due to the preponderance of sewage leakage into the groundwater system, "smoke testing" of sewers routinely misses many to most of the leakage points that exist. This is especially true for leakage points that are submerged by sewage and those that are on the lower portions of the pipes. Leakage points that are detected by smoke testing are commonly near the tops of the sewer lines and are likely to be important points where waters infiltrate into the sewers during storm events.

On page 2-3 of the ESI (2010) report we find the following statement: *"Karst features, such as springs, losing streams, sinkholes, and caves are common in this region. Although no karst features have been identified in the proposed project area, in the event one is discovered within three hundred feet of the construction area, all construction activities in the vicinity will halt and the U.S. Fish and Wildlife Service will be notified of the discovery. Construction activities in the area will not resume until authorized by the U.S. Fish and Wildlife Service."*

Unfortunately, the engineer with ESI does not understand karst. The entire area underlain by the Boone Formation and served by the Marble Falls sewer system is karst and in fact includes one of the major springs of North Arkansas. The limestone bedrock is highly modified by solution and a well-developed and hydrologically well-integrated groundwater system exists in the subsurface. Furthermore, the engineer misunderstands the role of the U.S. Fish and Wildlife Service in karst areas. This agency's involvement is limited to issues that involve species listed under provisions of the Endangered Species Act. There are no such species currently known to exist within the area served by this sewer system.

Current Condition of the Sewage System

ESI (2010) assessed conditions in the existing Marble Falls sewer system. The system includes two lift stations. Lift station 1 has 18 residential customers and 3 commercial customers. This is the lift station that was discharging raw sewage into the groundwater system feeding both Upper and Lower Dogpatch Springs in 2009. Lift station 2 has 7 residential and 3 commercial customers. Commercial customers connected to lift station 1 include a 24-unit apartment building and a closed business. Commercial customers for lift station 2 include The Hub Convention Center/Scooter's Restaurant, the Hub Motel (45 rooms), and Shepherd's Fold Family Recreation Center.

ESI (2010, page 3-51) reports that average monthly water usage in 2008-2009 for the water system that supplies all of the sewage connections was 7,600 gallons per customer per month or 235,600 gallons per month. If we compare this to typical residential water use values of 75 gallons per capita per day, the mean usage rate is equal to about the amount of water that would be used by a residential population of 100 people. This indicates that none of the commercial customers are routinely large water users.

ESI (2010, page 3-6) reported a total of 16,026 feet of gravity sewer laterals with a total of 89 manholes. In addition there are two force main lines. The gravity sewer lines are concrete and asbestos concrete pipe. The majority of the sewers are 6 inch diameter lines; current requirements typically require a minimum of 8 inch diameter pipe

(ESI 2010). The force main from lift station 1 is about 1,900 feet long, and the force main from lift station 2 is about 4,500 feet long. The total length of gravity and force main sewers is thus about 22,426 feet.

The sewer system was constructed in the 1960s to serve the Dogpatch Theme Park. This was a large development that never achieved the optimistic plans of the developers. The park closed permanently in 1993. The scale of the sewer system vastly exceeds the scale of a system needed to service 31 residential and small business customers. A result has been the unwillingness and/or financial inability of the sewer district and/or its customers to adequately fund an entity capable of maintaining and adequately operating the sewer system. These problems are magnified by:

- Initial design and construction that, at least in some respects, did not meet current standards.
- Years of system neglect.
- Worn out and broken equipment and sewage lines.

The ESI report (2010, pages 3-7 to 3-21) details smoke testing of segments of the gravity sewer lines. A total of 27 of the 89 manholes were smoke tested to identify leaks. This testing identified the following problems:

- Service lines are the sewer lines that extend from a customer's site to one of the sewer districts lines. While most or all of these service lines probably were constructed by the Dogpatch developer, their maintenance is now the responsibility of the customer. Multiple service line leaks were noted associated with smoke testing of 3 manholes. Several service line leaks were noted associated with testing of 2 more manholes. One additional large leak from an unknown type of source was also detected.
- A total of 7 main line leaks were detected; one of which was reportedly fixed.
- Seven blockages or clogs, plus one more possible blockage or clog, were detected. Three of these were reportedly fixed.
- There were 19 broken or leaking manholes or manhole covers. Two of these were immediately adjacent to ponds or streams.
- Debris demonstrated that relatively recent sewer line overflows had occurred from at least 6 manholes.
- There were 4 stub-out that were leaking. These need to be sealed. A stub-out is designed for a future sewer line connection or was potentially a site where a sewer connection had previously existed.

The sewer system has a total of 89 manholes. Of these, 30% were smoke tested. In some cases testing one manhole provides adequate data on a segment of line that includes several manholes, yet a number of additional leaks would likely have been discovered if more of the manholes had been smoke tested.

At discussed earlier, smoke testing will not identify leaks below the water level in a manhole or in a sewer. Additionally, in a karst setting, many to most of the leaks go rather directly down into the groundwater system and the smoke testing is ineffective in locating them. If we assume that "several" equals 3 and "multiple" equals 5, then a total of 67 problems were identified in the sewer lines. That is about two problems per customer when only 30% of the manholes were smoke tested.

Force main 2 extends for about 4,500 feet from lift station 2 to the treatment plant. ADEQ (2010) reports the distance to be about 3,800 feet; our distance of 4,500 feet was measured from the map included with the ADEQ (2010) report. Lift station 2 is immediately adjacent to one of the ponds on Mill Creek within the former Dogpatch Theme Park. Based on a photo on page 3-24 of the ESI (2010) report the distance from the lift station to the pond appears to be about 15 to 20 feet and the lift station is located so that any overflow from it will flow directly into the pond. ESI (2010, page 3-26) made the following observation about Force Main 2.

"Because the entirety of the force main is located below ground, no detailed evaluation of the force main or exact location could be determined using the methods available for the preparation of this report. However, by situating an observer at the concrete inlet box west of the treatment unit during operation of pumps a lift station 2, it was determined that none of the effluent being pumped actually reached the treatment site. It is suspected that the effluent is leaking from one or more locations along the length of the force main. The location of the leak(s) was unable to be determined. The release of untreated wastewater through one or more leaks along the length of Force Main 2 is unacceptable, and if Lift Station 2 is to remain in operation, repair or replacement of Force Main 2 will be required. A previous leak in Force Main 2 was previously located and repaired by the District. Due to the age of the force main and the history of previous leakage, it is anticipated that locating and repairing the existing leak(s) will only be a temporary solution, and development of additional leaks in the near future is highly likely. For this reason, if Lift Station 2 is to remain in operation, replacement of the entire force main is recommended."

ADEQ introduced one pound of fluorescein dye mixture (dye equivalent not identified) at lift station 2 on July 26, 2010 at 6:45 PM and the pump at the lift station began to operate within 30 minutes of the time of dye introduction. ADEQ (2010) reports that they had personnel stationed at the water treatment plant and no visible dye appeared at that station during the remainder of July 26. However, ADEQ (2010) reports that fluorescein dye was visible at the treatment plant in less than 18 hours after dye introduction.

ADEQ (2010) reports introducing 1.5 pounds of rhodamine dye mixture (dye equivalent not identified) at lift station 1. There are several rhodamine dyes; hopefully the dye used by ADEQ was rhodamine WT. ADEQ reports that the first arrival of rhodamine dye at the sewage treatment plant was six days later. ADEQ (2010) states:

"The lengths of time between the dye injection (sic) and recovery (sic) at the WTP seems to be extensive. A clogged, leaking sewer system may account for the long time lapse between injection of dyes and recovery at the WTP."

The statement by ADEQ about a clogged, leaking sewer system being responsible for such slow travel rates is more likely than not to be correct.

The ESI (2010) report shows a dilapidated and inadequately functioning sewage treatment plant. A treatment plant needs for all of its component parts to function properly and the Marble Falls plant clearly does not meet this requirement. Without major work there is no reason to expect the treatment plant to be capable of discharging adequately treated effluent to the associated "polishing pond".

The author visited the treatment plant site on the afternoon of September 3, 2010. The plant and the "polishing pond" are both underlain by the St. Joe Limestone member of the Boone Formation. The St. Joe Limestone at this location is located between elevations of approximately 1005 and 1055 feet and it dips toward the northeast (Hudson et al. 2004). At the time of the visit equipment at the plant could be heard running. The growth of weeds and grass at the site and on the access road indicate that the site is infrequently visited.

The "polishing pond" has had no reported discharge to surface water since May 31, 1994 (ESI 2010, pages 3-45 & 3-46). At the time of the ESI visit there was some water in the pond, but its level was far below the outflow level.

Nelson Engineering (2001 and 2003) prepared evaluation reports on the wastewater stabilization pond (polishing pond) on behalf of the Marble Falls Sewer Improvement District for submission to ADEQ. The conclusion by LaVerne Nelson (Nelson Engineering 2001, page 4) was:
"The amount of pond leakage, if any, is very small and, I believe, is within reasonable tolerances."
His statement is based upon very limited data and measurements made over a 12-day period. His conclusion is not supported by credible data and is grossly in error. This will be demonstrated in the following section of this report.

Amount of Untreated and Inadequately Treated Sewage Entering the Karst Groundwater System

The calculated mean annual amount of untreated and inadequately treated sewage entering the karst groundwater system from the Marble Falls sewage system is based on the following values.

1. Mean monthly sewage production equals 235,516 gallons per month for the system. ESI (2010, page 3-51). Nelson Engineering (2001, p. 2) used a value of 206,800 gallons per month. The values are similar. In my calculation I will use the more recent value of 235,516 gallons per month (2,826,192 gallons per year).
2. Mean annual precipitation (based on values for Harrison, Arkansas) is 43.71 inches. This value is found in Exhibit B to Nelson Engineering (2001). Exhibit B is data from U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS). Harper et al. (1981, page 2) state that the mean annual

precipitation is 43 inches. In my calculation I will use the 43.71 inches per year value.

3. Mean annual evaporation (based on values for Harrison, Arkansas) is 41.86 inches. This value is found in Exhibit B to Nelson Engineering (2001). Exhibit B is data from the NRCS. Schroeder (1982, page 13) shows a map indicating evaporation equals approximately 59 inches per year from National Weather Service Class A evaporation pans. A correlation factor of 0.70 is routinely applied to data from Class A evaporation pans to estimate evaporation from lakes; see Linsley et al. (1958, page 104). 59 inches per year X 0.70 = 41.3 inches per year. This is similar to the NRCS value. In my calculation I will use the 41.86 inches per year value.
4. The area of the water surface in the pond is 1.40 acres. This value is found in Nelson Engineering (2001, Exhibit E) and in ESI (2010, page 3-45).

Given the above values I made the following calculations.

- The annual addition of sewage to the polishing pond would equal 235,516 gallons per month (2,826,192 gallons per year) if there were no leakage out of any of the sewers or sewer connections. For a pond of 1.40 acres this would equal a depth of 74.40 inches per year.
- Precipitation to the pond would equal 43.71 inches per year. For a pond of 1.40 acres this would equal 1,655,473 gallons per year.
- Total inflow to the pond (excluding runoff into the pond from adjacent lands) = 74.40 inches + 43.71 inches = 118.11 inches. For a pond of 1.40 acres this would equal 4,473,298 gallons per year.
- Loss from the pond by evaporation would equal 41.86 inches per year. For a pond of 1.40 acres this would equal 1,585,406 gallons per year.
- Net discharge from the sewage system to groundwater equals 118.11 inches – 41.86 inches = 76.25 inches. For a pond of 1.40 acres this would equal 2,887,893 gallons per year or approximately 2.9 million gallons per year.

In the above calculations I have not estimated the amount of runoff water that enters the pond. Since the pond is filled with sewage the runoff water would also become sewage. We also have not estimated transpiration by plants along the edge of the pond that would withdraw some water from the pond. The volume of runoff into the pond undoubtedly exceeds the volume of sewage removed by transpiration.

There has been no surface discharge of sewage or sewage effluent from the pond since May 31, 1994. There are four reasons for this.

- The numerous leaks in the Marble Falls sewage lines and connecting service lines result in the direct discharge of raw sewage into the groundwater system.
- In wet periods these sewer line leaks result in raw sewage discharges through manholes and broken pipes.

- Equipment and maintenance failures have resulted in overflowing lift station(s) that have discharged (in the case of lift station 1) for months at a time to a losing stream that directly recharges the groundwater system.
- The "polishing pond" leaks sewage or sewage effluents into the karst groundwater system. This groundwater system conveys the leakage to Mill Creek or to one or more tributaries to Mill Creek.

During wet periods surface water and water in the soils infiltrates into the sewer system through the broken manholes and sewer lines. This increases the volume of sewage that ultimately enters the groundwater system but concurrently dilutes the raw sewage.

Mean annual precipitation in the area exceeds mean annual evaporation by about two inches. As a result, even without the addition of any sewage or sewage effluent to the "polishing pond" it would have discharged water to the downstream surface channel under many conditions during the last 16 years unless it leaked. Dye tracing by ADEQ (2010) demonstrated that at least some sewage from lift stations 1 and 2 does reach the treatment plant and from that plant would discharge into the "polishing pond". The fact that the pond routinely receives some sewage from the sewer system and that the pond has not discharged any water to the surface during the last 16 years demonstrates major leakage from this pond into the groundwater system and ultimately into Mill Creek or one or more of its tributaries.

The "polishing pond" was reportedly lined with clay (Nelson Engineering 2003). There are no available data indicating that the clay was appropriately compacted. Furthermore, the pond is never full. Clay liners that are allowed to dry and go through freeze/thaw conditions during the winter or are penetrated by plant roots routinely experience several orders of magnitude increases in permeability. Ponds overlying soluble rock units are notorious for leaking into groundwater supplies and this "polishing pond" is clearly no exception. If the pond is to be used in the future as part of a sewage treatment system a synthetic liners must be installed to prevent leakage to groundwater. The major cost of rehabilitating the "polishing pond" is not included in any of the alternatives considered by ESI (2010).

Recommended Solutions in the ESI (2010) Report

The ESI (2010) report indicates (page 3-51 and Appendix B) that total revenue for the sewage district in 2008 was $7,688.45 and $6,310.68 in 2009. With increased rates the engineer estimates that total annual revenue should be approximately $19,864.

The ESI (2010) report dismisses on-site sewage systems in one paragraph on page 5-2. There are many more advanced systems than the simple septic tanks the engineer considered. Such a system or multiple systems would provide better water quality protection than any of the four patch-up strategies outlined by the engineer. These patch-up strategies have estimated costs ranging from about $58,000 to about $571,000.

None of the strategies outlined by ESI (2010) would adequately correct the pollution problems being caused by the Marble Falls sewage system. The least expensive alternative proposed by the engineer would simply relocate and replace lift station 1. It would not repair any of the myriad leaks in the system, repair or replace the treatment plant, or repair the "polishing pond". This alternative would simply continue the Marble Falls sewage system practice of discharging raw sewage into the karst groundwater system and ultimately into Mill Creek. The cost of the next least expensive alternative is about $375,000. As noted earlier, the major cost of rehabilitating the "polishing pone" is not included in any of the alternatives considered by ESI (2010).

Results of ADEQ Dye Trace

I have been involved in about 4,000 groundwater traces using fluorescent tracer dyes. As a result of this experience I have identified several short-comings in the tracer test conducted by ADEQ. I will identify and discuss each of these. However, the tracing work conducted by ADEQ resulted in two important findings that will also be discussed.

Study Deficiencies

ADEQ (2010) introduced a total of 1.5 pounds of fluorescein dye mixture at two points in the Marble Falls sewer system. The amount of dye in the dye mixture (known as the dye equivalent) was not identified. Aley (2002) reports that the dye equivalent in fluorescein mixtures on the market ranges from 2 to 80% so the amount of dye used is unclear. Failure to detect fluorescein dye at some sampling stations or during some sampling periods is almost certainly a result of the use of an insufficient quantity of dye.

ADEQ also reported that they used 1.5 pounds of rhodamine dye. There are several rhodamine dyes. Of these, rhodamine B would be totally unsuited to the tracing through the groundwater system. Alternately, rhodamine WT would be a reasonable choice. Hopefully ADEQ used rhodamine WT. Again, the dye equivalent percent in the dye mixture used was not indicated in the ADEQ work. A common dye equivalent is 20%, but dye equivalents as low as 3% are available on the market (Aley 2002).

The purposes of the tracing work were not stated in the report (ADEQ 2010). The placement of automatic water samplers at Lower Dogpatch Spring and on Mill Creek near the Spring Valley (Newton County Route 82) crossing indicates that potentially detecting dyes at these points was probably a major consideration. If so, then the quantities of dyes used were far too small even if the dye equivalent in the fluorescein mixture had been 75% and had been 20% in the rhodamine WT mixture. The amount of dye needed increases as the number of leaks in the system increases. The amount of dye needed also increases under summer conditions when soils and the underlying residuum are dry; the ADEQ trace was conducted during late July and early August.

While two of the dye introductions were made at lift stations, one introduction of half a pound of fluorescein was made at Manhole 28 where it was flushed with only 20 gallons of water. While this amount of flush water would be adequate if there were at least a few gallons per minute of flow in the sewer the report does not indicate that this was the case. If there were no flow in the sewer, the use of only 20 gallons of flush water would be insufficient under summer conditions to flush the dye through a leak or leaks and into the groundwater system.

The amount of dye needed for tracing is also a function of the sampling method used. The ADEQ work relied on water samples. Much professionally directed groundwater tracing places primary reliance upon activated carbon samplers and secondary reliance on water samples. Activated carbon samplers are continuous and accumulating samplers that adsorb and retain tracer dyes. The concentration of dye detected in activated carbon samplers in place at a spring or stream for a week routinely is about 400 times greater than the mean dye concentration in water samples. The concentration factor is greatest when dye concentrations in water are small. During the trace by Aley (2009) of sewage discharging from lift station 1 the concentration of rhodamine WT dye in the elutant from an activated carbon sampler from Mill Creek near the Buffalo River in place for three days was 110 times greater than the mean dye concentration in water samples from that station for the same period. Since ADEQ planned to rely on water samples for dye detection they should have introduced a much larger volume of dye than the amount used.

The amount of dye needed for a trace is also a function of the analytical method used. The most appropriate analytical equipment permits the operator to set the bandwidth separation between excitation and emission fluorescence and then synchronously scan samples over a couple of hundred nanometers and print out a graph of emission fluorescence. Only a few laboratories have such equipment and personnel experienced in its use. At low dye concentrations the fluorescence equipment used by ADEQ cannot discriminate between dyes and background fluorescence due to other fluorescent materials including natural compounds from vegetation and other sources. Some of the low concentration fluorescein detections reported by ADEQ were undoubtedly due to materials other than fluorescein. This occurs when the detection limit established by the laboratory is based on spiked samples in reagent water since such mixtures lack the fluorescent materials routinely present in natural systems. Fluorescence intensity due to these natural materials can vary substantially among sampling stations and through time at individual sampling stations.

Substantial portions of the sewage system, including the treatment plant and "polishing pond", are likely to recharge groundwater supplies that discharge from the groundwater system at locations where discharging dyes would not be detected by a dye sampling station on Mill Creek near the Spring Valley Road crossing. As an illustration, the stream immediately east of the "polishing pond" joins Mill Creek about 3,000 feet downstream of the point where Mill Creek is crossed by Spring Valley Road. Groundwater discharges of raw or partially treated sewage from the Marble Falls sewage system into this stream could well occur and testing for this possibility should have occurred during the ADEQ dye tracing study.

Important Findings

Despite the short-comings in the ADEQ (2010) report, their tracing study yielded two important findings.

First, the ADEQ study demonstrated that some of the rhodamine WT dye introduced at lift station 1 ultimately arrived at the sewage treatment plant. The travel distance through the sewers via force main 1 and lateral 1 was about 6,700 feet (ADEQ 2010). The ESI (2010) report states that most of the sewer lines are six inch in diameter. If so, they have a capacity of about 1.47 gallons per linear foot for a total capacity of 9,850 gallons between lift station 1 and the treatment plant if the entire line were filled with water. The ADEQ (2010) report states that rhodamine WT first arrived at the sewage treatment plant six days after introduction.

The entire sewer line between lift station 1 and the treatment plant would not be filled with water. If it were, and the dye took six days to reach the plant, this would indicate that the through-flow rate to the plant would not have exceeded 9,850 gallons divided by six days or 1,640 gallons per day. ESI (2010) calculated mean daily sewage production for the sewage system at 7,600 gallons per day. It is reasonable to estimate that at least half of this (3,800 gallons per day) should be conveyed by the sewer lines traced with rhodamine WT dye. Using these values, under the conditions tested, at least 57% of the sewage that should be transported by force main 1 and lateral 1 is lost to leakage into the karst groundwater system.

The second important finding was that fluorescein dye from lift station 2 first reached the sewage treatment plant between 4.75 and 18 hours after dye introduction. The 4.75 hour value is based upon a statement in the ADEQ (2010) report that they had a person at the treatment plant and no dye was observed during the remainder of July 26. The long travel time for this trace is inconsistent with a force main in proper condition. There are undoubtedly leaks and/or clogs along this force main. It was the conclusion of ESI (2010) that this force main would need to be replaced. This is a reasonable conclusion.

NPS Dye Sampling

The NPS monitored for tracer dyes at five sampling stations where the detection of tracer dyes from the ADEQ work was considered possible. Two of these stations were on Mill Creek, one station was Boiling Spring (a tributary to Mill Creek), one was on the Buffalo River, and the last was at a spring tributary to the Buffalo River. One of the Mill Creek stations was at the point where that stream is crossed by Spring Valley Road.

ADEQ introduced fluorescein and rhodamine (probably rhodamine WT) dyes on July 26, 2010. All of the NPS dye sampling stations were in operation on or before July 26 except for the spring tributary to the Buffalo River where sampling began on July 27. All sampling placed primary reliance upon activated carbon samplers. Collected samplers and grab samples of water were analyzed by the Ozark Underground Laboratory using the same protocol as outlined in Aley (2009). As of the date of this report, samples collected through August 3, 2010 have been analyzed. No fluorescein or rhodamine WT dye has been detected.

Summary of Findings

1. Almost all of the Marble Falls sewage system is underlain by a well developed and rapidly transmissive karst groundwater system that contributes water to Lower Dogpatch Spring and other springs that ultimately yield water to Mill Creek. Lower Dogpatch Spring is one of the largest springs in the Buffalo River basin; it discharges to Mill Creek within the area of the former Dogpatch Theme Park.
2. About 75% of the annual precipitation that falls on karst areas in the Ozarks moves into and through the groundwater system before reaching one of the perennial streams in the area. Travel rates in the groundwater system are routinely hundreds to thousands of feet per day. These values are applicable to the Marble Falls area.
3. It is difficult to locate most leakage points from sewer lines and sewage ponds in karst landscapes such as the area served by the Marble Falls sewer system. Most of the leakage moves downward into the karst groundwater system without first surfacing somewhere near the leakage point. Smoke testing will not discover most of these leaks.
4. The Marble Falls sewage system is in extremely bad condition due to, among other things, years of system neglect and worn out and broken equipment and sewage lines. Based upon the ESI (2010) report there are numerous leaks in the system and the treatment plant is currently unable to provide adequate wastewater treatment.
5. All of the sewage discharged from customers connected to the Marble Falls sewage system enters the karst groundwater system as raw sewage or as a combination of raw sewage and inadequately treated sewage.
6. Much of the raw sewage that enters the karst groundwater system enters through broken sewer lines.
7. Discharge from the treatment plants is designed to go through a flow-through "polishing pond" and then discharge to a surface stream channel. There has been no surface discharge from this pond since May 31, 1994. A water balance analysis showed that the pond leaks appreciable volumes of water into the karst groundwater system and through that system ultimately into Mill Creek and then the Buffalo River. An engineering report by Nelson Engineering (2001) concluding that the amount of pond leakage, if any, was very small and within reasonable tolerances lacks credibility and is inconsistent with data included in the engineer's report.
8. Mean raw and/or inadequately treated sewage discharge from the sewage system is approximately 2.9 million gallons per year (8,000 gallons per day).

Conclusions and Management Recommendations for the National Park Service

The NPS is responsible for protecting public health and safety on the Buffalo National River, and Mill Creek is a major tributary to the river. The discharge of untreated or inadequately treated sewage into Mill Creek poses a health risk, and potentially a health hazard, to Park visitors.

The Marble Falls sewage system serves an average population equivalent of about 100 people. There are occasional events held at the businesses connected to this sewer system that are attended by large numbers of people. Since all sewage generated in the service area for the sewer system enters the karst groundwater system as raw or inadequately treated sewage, the risk that serious pathogens may be present increases with both the quantity of sewage and the number of potential carriers of pathogens.

Coliform bacteria standards provide guidance for closing water bodies to whole body contact. Except during storm runoff periods the coliform concentrations in lower Mill Creek and on the Buffalo River are not high enough to require the closure of the water bodies to whole body contact. However, the management challenge posed by the raw and inadequately treated sewage discharges at the Marble Falls sewage system is that human sewage discharges pose a greater health risk to people than do animal waste discharges. Additionally, public perception places greater concern on human wastes than animal wastes.

I recommend that NPS management of this matter recognize the following important (and in some respects unique) features of the situation.

- The Marble Falls sewer system is underlain by a well developed karst system that is capable of transmitting pathogens derived from the sewer system and inadequate treatment facilities into and through the aquifer with ultimate discharge to Mill Creek and the Buffalo River.
- A substantial part of the sewage that enters the Marble Falls sewer system discharges as raw sewage into the underlying groundwater system. The sewage that reaches the treatment facility does not receive adequate treatment because important parts of the equipment are not functional. Discharge from the treatment plant is designed to enter a "polishing pond". This pond leaks substantial volumes of inadequately treated wastewater into the underling karst aquifer.
- There is no credible reason to expect significant improvements in conditions at the Marble Falls sewage system in the near future. Furthermore, based upon past performance, it is not clear that state or local officials will take actions to stop the introduction of sewage into the groundwater system and ultimately into Mill Creek and the Buffalo River.

Given the above conditions, while coliform bacteria standards alone do not warrant closing some portion of the Buffalo River downstream of Mill Creek to whole body contact, an unnatural health risk does exist for visitors to this portion of the Park. At a minimum, a strategy of effectively and routinely informing visitors to the Park and the general public about this health risk is warranted.

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